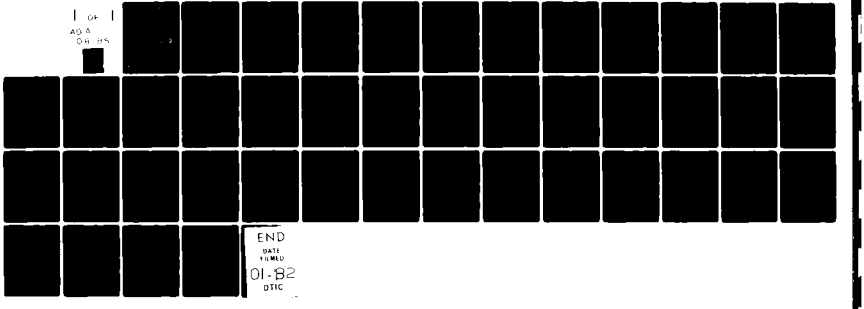
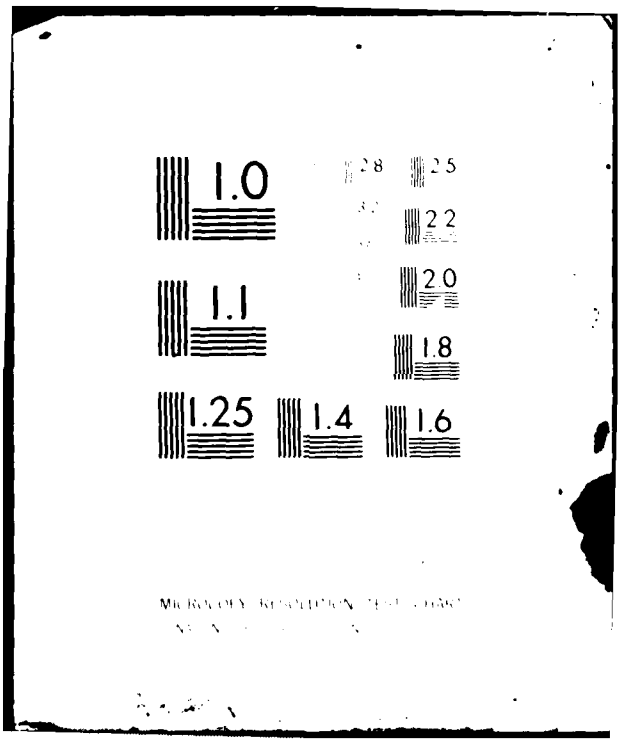
AD-A108 185 CLARK UNIV WORCESTER MA F/G 4/1
ELECTRON TRANSPORT AT HIGH ALTITUDE.(U)
SEP 80 M KANAL, A F TORABI F19628-79-C-0008
UNCLASSIFIED AFGL-TR-80-0314 NL



END
DATE FILMED
01-82
DTIC


1.0
2.8
2.5
2.2
1.1
2.0
1.8
1.25
1.4
1.6

(12) LEVEL II

AFGL-TR-80-0314

ELECTRON TRANSPORT AT HIGH ALTITUDE

Madhoo Kanal
Ahmad Farokh Torabi

Clark University
950 Main Street
Worcester, Massachusetts 01610

Final Report
November 1978 - June 1980

Date of report
30 September 1980

Approved for public release; distribution unlimited

AIR FORCE GEOPHYSICS LABORATORY
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
HANSCOM AFB, MASSACHUSETTS 01731

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER AFGL-TR-80-0314	2. GOVT ACCESSION NO. AD-A108 185	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) ELECTRON TRANSPORT AT HIGH ALTITUDE		5. TYPE OF REPORT & PERIOD COVERED Final November 1978 - June 1980
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Madhoo Kanal and Ahmed Farokh Torabi		8. CONTRACT OR GRANT NUMBER(s) F19628-79-C-0008
9. PERFORMING ORGANIZATION NAME AND ADDRESS Clark University 950 Main Street Worcester, MA 01610		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 61102F 2311G2BB
11. CONTROLLING OFFICE NAME AND ADDRESS Air Force Geophysics Laboratory Hanscom AFB, Massachusetts 01731 Monitor/Susan C. Bredesen/PHG		12. REPORT DATE 30 September 1980
		13. NUMBER OF PAGES 45
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

electron flux
electron transport
transport equation
transport flux

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

An infinite medium Green's function is constructed for the boundary value problem of electron transport along the magnetic field lines of the earth in an inhomogeneous anisotropically scattering medium.

The goal of calculation is to obtain the photoelectron energy flux as a function of altitude, energy and the invariant latitude. The problem involves obtaining the solution for a Boltzmann type equation using a combination of analytic and numerical techniques.

DD FORM 1 JAN 73 1473

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

Detailed transport calculations of photoelectron energy degradation processes via both inelastic collisions with neutral and interaction with the ambient plasma are performed.

A comparison is made of fluxes obtained with transport neglected (local fluxes) with those obtained with transport included (transport fluxes).

The local fluxes are found to be larger than transport fluxes at low altitudes, while at high altitudes the transport fluxes are larger than local fluxes.

As an illustrated calculation of our results of photoelectron fluxes, we present the volume excitation rates of several lines and bands of the day airglow. We also compare our results of excitation rates with theoretical and experimental data obtained in the existing literature.

NOTE

The final report presented here constitutes the finality of our commitment to Air Force under contract number F19628-79-C-0008. Needless to say that we are very grateful to the Air Force for this support which has culminated in a dissertation for a Ph.D. degree at Clark University. We further believe that the combined efforts of my graduate student, A.F. Torabi, and myself has resulted in producing a final product which is unique and useful to the solution of practical problems of interest to the Air Force and other defense branches of the U.S.A. Perhaps it is important and correct to point out that our work constitutes the basis of understanding the full transport problem of photoelectrons when the inclusion of electric and magnetic fields is contemplated explicitly. The new methodologies developed by us and discussed in the report seem to make that problem (inclusion of fields) tractable. Finally we wish to point out that collaboration with Dr. William Burke of A.F.G.L. was of very high quality and we remain thankful to him.

Madhoo Kanal
Principal Investigator

ACKNOWLEDGMENTS

It gives me great pleasure to thank Professor Madhoo Kanal for his guidance, advice and many fruitful discussions during the course of this work. I also would like to thank Professor John Davies for critically reading the manuscript and for helpful discussions. My thanks are due to Dr. William Burke at AFGL, and Dr. Walter Hoegy at GSFC for helpful correspondence.

Finally, I would like to express my deepest gratitude to my mother Mrs. Mahin Torabi and my wife Sheida for their unselfish help and support throughout my studies.

Financial support from the Air Force Geophysics Laboratory and from Clark University is gratefully acknowledged.

Ahmad Torabi

PREFACE

Since there is no lexicon describing electron transport in the terrestrial atmosphere, some of the terms used in this dissertation are those borrowed either from radioactive transfer or neutron diffusion theory. Furthermore, while the mathematics involved in solving the transport equation may be somewhat strange to most readers, the palpability of the procedure is maximized by correlating various quantities to physical processes.

The method of treating the electron transport equation considered here was essentially developed during and after World War II atomic bomb events and later during the development of neutron chain reactors. The basic idea may be attributed to Schwartz (1) who introduced the distribution theory in the fourier transform of non-classical function. It was Dirac (2) who applied Schwartz's distribution theory to physical problems in quantum mechanics. He made the fundamental observation that although the distributions (such as Dirac's delta function) had no physical meaning by themselves alone, they had well defined meaning when used as probability distributions. This idea was carried over by Van Kampen (3) in the solution of wave propagation problems in plasmas.

---

1. Schwartz, L., Theorie des Distributions, Vol 1, Hermann, Paris (1950).

2. Dirac, P.A.M., The Principle of Quantum Mecahnics, Oxford University Press (1950).

3. Van Kampen, N.G., On the Theory of Stationary Waves in Plasmas, Physica 21, 949 (1955).

Thus both Dirac and Van Kampen demonstrated that Schwartz's distribution was a powerful tool in dealing with non-classical and classical problems of theoretical physics. Unfortunately, Van Kampen's procedure lacked fundamental structure. This situation was ameliorated by Kenneth Case (4) who recognized the similarity of the spectrum of the Vlasov equation and the linearized Boltzmann equation. He also recognized this isomorphism between the transport equation and the linearized Boltzmann equation.

Case then developed what is now well known as the Normal Mode Expansion Technique. This technique, as powerful as it is, lacks flexibility in adapting it to non-separable partial differential equations. Again, this situation was improved by Case who, drawing a parallel between the methods of classical electrodynamics and the neutron diffusion theory, developed the Green's Function Approach.

He demonstrated that Schwartz type distributions were not only fundamental building blocks of the Boltzmann type equation, but indeed were also complete. The latter point was illustrated by obtaining the spectral representation of Green's function. Another virtue of the distributions occurring in the Green's function was that, not only were they complete, but they also formed an orthogonal set. Thus, the orthogonality property permitting one to solve multi point boundary value problems in this work is pursued in the same spirit as Dirac's probability distribution in quantum mechanics, as Van Kampen's electrostatic waves in plasmas, and as Case's normal modes in neutron diffusion theory.

---

[4]Case, K.M., Linear Transport Theory, Addison Wesley, Reading, Massachusetts (1967).

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

This work deals with a method of calculating electron transport and its application to the study of photoelectrons in the upper terrestrial atmosphere (100 KM and up). The primary result of this work is a calculation of the photoelectron energy flux as a function of electron energy and altitude along a given magnetic field line of the earth. In our calculation we consider various degradation processes of primary photoelectrons such as elastic and inelastic collisions with neutral atoms and molecules and interactions with the ambient thermal electron plasma. The inhomogeneity of the atmosphere, anisotropic scattering and sphericity of the earth are taken into account. In order to obtain these results it was necessary to develop a number of new analytical and numerical techniques which are also applicable to the solution of a much wider variety of transport calculations. The technical details of this work have been published in two papers described at the end of this section. Chapter II is the conclusion and a discussion of our results.

The primary source of electrons is the photoionization of neutral species by the incident solar radiation (photons). The solar spectrum between soft X-rays and the extreme ultraviolet EUV (14-1100 A^{o}) produces these fresh photoelectrons. We assume that the photoelectrons are produced isotropically, i.e., their velocity vectors will not have any preferred direction. The range of energies of such photoelectrons may vary between 0 and 200 ev. Their energy spectrum is referred to as primary electron spectrum (PES).

In this work we have assumed that the atmosphere consists of four

species (N_2, O_2, O, He). For the altitudes considered these species are dominant in the production and subsequent scattering of photoelectrons. In our calculation we consider photoionization processes which leave the target in excited states as well as those which leave it in the ground state.

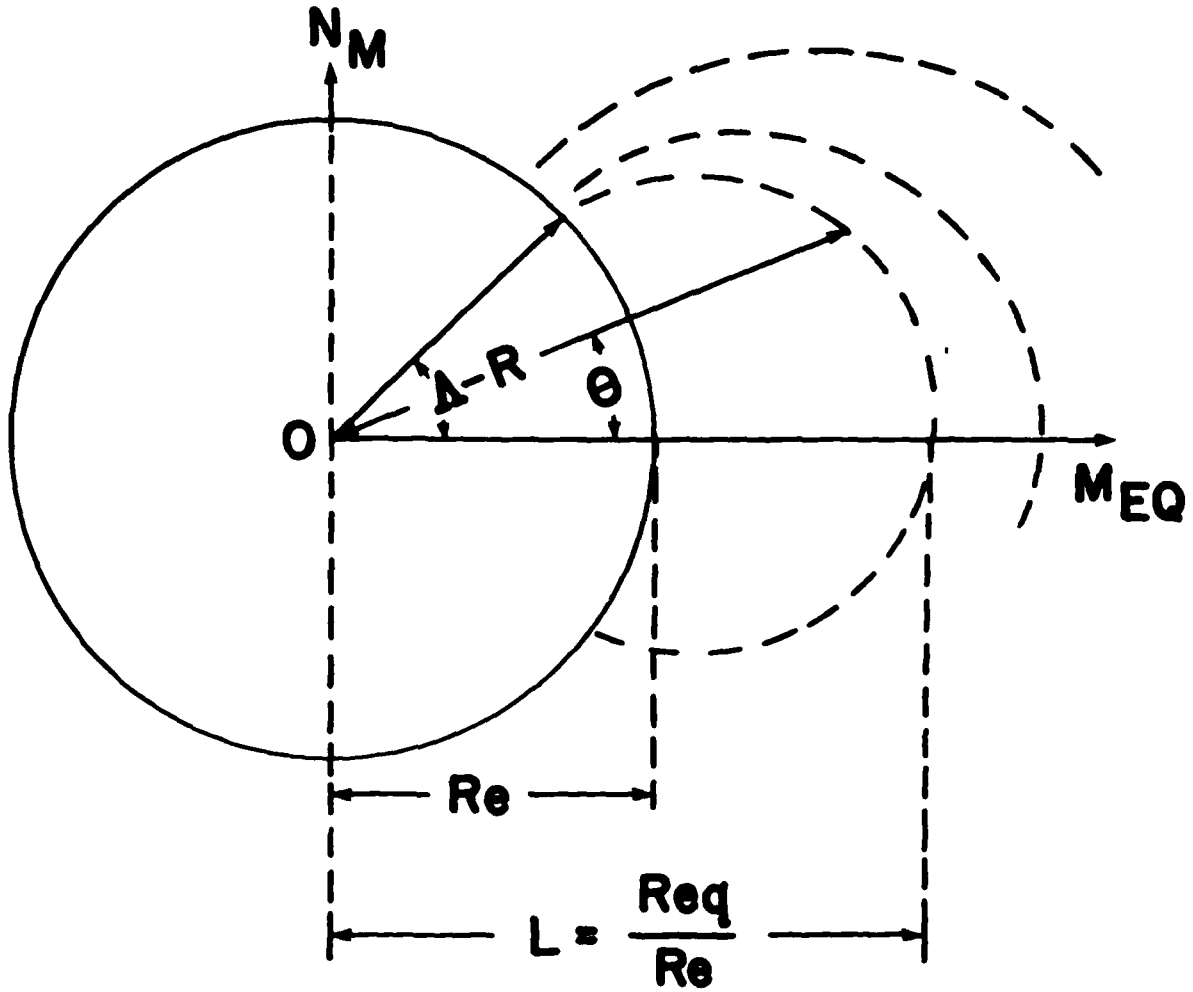
In the real atmosphere, these photoelectrons spiral along the magnetic field lines of the earth. As they do so they undergo collisions with neutral species and interact with the ambient plasma.

The maximum radius of gyration of an electron about a magnetic field line is approximately one meter (in the range 0 to 200 ev), which is less than the characteristic scale height H or mean free path of an electron. In consequence, the gyrating electrons will traverse a uniform medium in one cycle of revolution. This permits us to consider the motion of electrons about the field lines by analyzing the motion of their guiding centers along the field lines. This is known as the guiding centre approximation (1).

We have assumed Chapman's (2) dipole formula for the radial distribution of the earth's magnetic field, which is described in terms of the invariant latitude (Λ), or McIlwain Coordinate L, (L shell). The earth, its magnetic field lines and the invariant latitude are shown in Fig. 1.

The number of photoelectrons found at any time in a volume element at a certain altitude (with energies in a specified energy interval and velocity vector in a specified solid angle) is determined by the balance between production (source) processes and loss (sink) processes.

By sink we mean various processes contributing to the energy degradation of primary photoelectrons. There are essentially two kinds of sinks corresponding to elastic and inelastic interactions. In the category of



$$R = Re\, L\, \cos^2(\theta)$$

$$L = \frac{1}{\cos^2(\Lambda)}$$

Figure 1. The earth and its magnetic field lines.

elastic interactions we include scattering by neutrals in which there is negligible momentum transfer. We also include the electron-ambient plasma coulomb interactions. In the inelastic interactions with neutrals an electron may excite the species or may ionize and excite it.

By source we mean various processes contributing to the production of electrons. In addition to the PES, a second source of electrons is that due to electron-neutral ionization collisions. The spectrum of these secondary electrons (SES) is determined by the threshold ionization energies of neutral species and the state in which the ionized species is left.

There is still another source term besides the PES and SES, which we refer to as the emission term. There are three processes which contribute to this emission term. One is the cascading of higher energy electrons in which the electrons take discrete jumps in energy by exciting neutral species and also redistributing their pitch angles. (The pitch angle is the angle between electron velocity and the field line.) The second is the elastic scattering of electrons by neutral species. In elastic scattering by neutral species the electrons redistribute their pitch angles without an appreciable loss of energy. The third process is the scattering of electrons by the ambient plasma in which there is an energy loss (ΔE) and redistribution of electron pitch angles.

The electron transport equation emerges when we balance the source terms with the sink terms plus an advective. This advective is equal to the divergence of the electron current density (in phase space) and contributes to the loss of electrons. This term corresponds to transport effect.

For the altitude considered in this work the dominant interactions of

photoelectrons are with neutral species and the ambient plasma. Thus we neglect the photoelectron-photoelectron interactions. As a result, the transport equation is a linearized time-independent Boltzmann type equation. The technique of solving this equation is an extension of a Green's function approach which was first developed by Case (3).

When the advective term is neglected we are said to use the local hypothesis.

We define the electron energy flux as the electron speed times the energy dependent electron density. In the present work we have made calculations of the electron energy fluxes for both the local and transport cases.

Previous authors have made theoretical calculations of photoelectron energy spectra under various special simplifying assumptions: Banks and Nagy (4), two stream approximations; Swartz (5), diffusion approximations; Cicerone et al. (6), Monte Carlo techniques; and Victor et al. (7), local hypothesis. However, in this work we consider the transport, account for the inhomogeneity of the atmosphere, and the anisotropic scattering of the photoelectrons. We also incorporate the sphericity of the earth in our calculations.

We assume linear anisotropic scattering of photoelectrons in our numerical calculations of the electron flux. However, this restriction is not inherent to our methodology of solution of the transport equation.

In Kanal and Torabi (8) we develop techniques for solving the boundary value problems of electron transport in an inhomogeneous, anisotropically scattering medium. In Torabi and Kanal (9) we develop the details of our method of studying electron transport by analytical and numerical techniques.

Finally, in Chapter II we present additional graphs illustrating the results of our calculation of the electron energy flux and discuss their physical significance. We also compute the volume excitation rate of important excited atmospheric species and compare our results with experimental and theoretical data obtained in the existing literature.

REFERENCES - CHAPTER I

1. Chandrasekhar, S., Plasma Physics, The University of Chicago Press (1962).
2. Chapman, S. The earth magnetism, New York, John Wiley & Sons, Inc. (1951).
3. Case, K.M., and P.F. Zweifel, Linear transport theory, Addison Wesley, Reading, Mass. (1967).
4. Banks, P.M., and A.F. Nagy, Concerning the influence of scattering upon photoelectron transport and escape, J. Geophys. Res., 75, 1902 (1970).
5. Swartz, W.E., Thermalization and transport of photoelectron, J. Geophys. Res., 81, 183 (1976).
6. Cicerone, R.J., W.E. Swartz, R.S. Stolarski, A.F. Nagy, and J.S. Nisbet, Thermalization and transport of photoelectrons: A comparison of theoretical approaches, J. Geophys. Res., 78, 6709 (1973).
7. Victor, G.A., K. Kirby Docken, and A. Dalgarno, Calculation of the equilibrium photoelectron flux in the thermosphere, Planet. Space. Sci., 24, 679 (1976).

8. Kanal, M. and A.F. Torabi, An infinite medium Green's function for the transport in an inhomogeneous anisotropically scattering medium, Transport Theory and Statistical Physics, 8(3), 169 (1979).

9. Torabi, A.F. and M. Kanal, Electron transport in an inhomogeneous anisotropically scattering medium, application to terrestrial atmosphere, Transport Theory and Statistical Physics, to be published in Volume 10, 1981.

CHAPTER II

CONCLUSION AND DISCUSSION

A. Introduction

In this chapter, we present transport calculations of photoelectron energy flux based on our methodology as described in References 8 and 9 of Chapter I. A further illustration of our results for the primary electron spectrum electron energy flux is given. Finally, we calculate the electron impact excitation rates of different emission lines in the day airglow. We also compare these excitation rates with corresponding experimental and theoretical data obtained in the existing literature.

In the following section we describe the transport equation and our methodology of its solution.

B. Photoelectron Transport Equation

The electron transport equation in an inhomogeneous anisotropically scattering medium along the magnetic field lines of the earth reads:

$$\mu \frac{\partial}{\partial X} I(X,E,\mu) + I(E,X,\mu) = \frac{W(X)}{2} \int_{-1}^{1} d\mu' \, f^{(e)} \, (\mu' \to \mu) I(X,E,\mu')$$

$$+ \nu_t^{-1} S(X,E,\mu) \qquad (1)$$

where

$I(X,E,\mu)$ = electron distribution function

X = relaxation length

E = electron energy (ev)

μ = cosine of pitch angle

$W(X)$ = electron albedo for single scattering

$P(E,N)$ = primary photoelectron spectrum (cm^3 sec ev str^{-1})

ν_t = total collision rate of electron with neutral species and ambient electrons

$S(X,E,\mu)$ = source function (secondary electron production)

$f^{(e)}(\mu' \to \mu)$ = elastic scattering phase function

The technique of solving Eq (1) is by the Green's function approach where the Green's function satisfies:

$$\mu \frac{\partial G}{\partial X}(X,\mu \to X_o \mu_o) + G(X,\mu \to X_o \mu_o) = \frac{W(X)}{2} \int_{-1}^{1} d\mu' f(\mu' \to \mu) G(X,\mu' \to X_o \mu_o) + \delta(X-X_o)\delta(\mu-\mu_o) \quad (2)$$

where

$G(X,\mu \to X_o,\mu_o)$ is the Green's function in which a model atmosphere has a plane source at $X = X_o$, ejecting electrons with a pitch angle μ_o with the boundary condition

$$\lim_{X \to \pm\infty} I(X,E,\mu) = 0 \quad (3)$$

We have developed the technique of a comparison Green's function approach to solve Eq (2). By knowing the Green's function one can obtain the solution of Eq (1), that is, the distribution function $I(X,E,\mu)$.

$$I(X,E,\mu) = \int_{-\infty}^{+\infty} dX' \nu_t^{-1} \int_{-1}^{1} d\mu' G(X',\mu' \to X,\mu)(S(X',E,\mu') + P(E,X')) \quad (4)$$

Equation (1) is solved for photoelectron energy flux $F(X,E,\mu)$ defined as

$$F(X,E,\mu) = 5.92 \times 10^7 \sqrt{E} \int_{-1}^{1} d\mu' I(X,E,\mu') \quad (5)$$

In the following sections we illustrate the spectrum of electron flux

F(X,E) as a function of altitude and different electron energies. Before we discuss the photoelectron energy flux, the primary electron spectrum is described and discussed for various altitudes, solar zenith angles and electron energies.

C. Primary Electron Spectrum

The primary photoelectron spectrum is calculated using the solar flux of Heroux and Hinteregger (1978) and the neutral model atmosphere of Hedin (1979). The solar spectrum between (14-1100Å) was used in the calculation of PES. Table 1 shows the model atmosphere used in this study. The photoelectron production rate is shown in Fig. 2 as a function of altitude and solar zenith angles. The energy spectrum of photoelectron (PES) is shown in Fig. 3 at solar zenith 30^{o}, Fig. 4 at 45^{o}, and Fig. 5 at solar zenith 60^{o} at altitude of 200 and 300 KM. The photoionization of atomic oxygen by the intense He II (304 A^{o}) solar line gives rise to electrons of energies 22.2, 23.9 and 27.2 ev, corresponding to production of O^{+} in electronic states 2P, 2D and 4S. The corresponding peaks occur in the spectrum of primary photoelectron which are shown in Fig. 3, Fig. 4 and Fig. 5.

The photoabsorption cross sections of Cook and Metzger (1964), Henry (1967) and Jacobs (1971), and branching ratios of Delgarno et al. (1964) and Tohmatsu et al. (1965) were used throughout the calculation of PES.

In the next section we discuss some of our results of photoelectron energy flux both for the local approximation and the transport calculation.

D. Electron Energy Flux

The electron energy flux as defined in Eq (5) is the product of electron

Table 1

Model Neutral Atmosphere[1]

LAT = 45 Z(KM)	F10.7 = 75 n(O)	AP = 4 $n(O_2)$	 $n(N_2)$	LT = 3 n(He)
200	3.40(09)	1.17(08)	2.11(09)	1.23(07)
300	2.68(08)	7.92(05)	2.64(07)	6.48(06)
400	2.55(07)	7.22(03)	4.32(05)	3.59(06)
500	2.62(06)	7.64(01)	8.07(03)	2.03(06)
600	2.88(05)	9.22(-1)	1.69(02)	1.17(06)
700	3.37(04)	1.26(-2)	3.96(00)	6.85(05)
800	4.19(03)	1.95(-4)	1.03(-1)	4.07(05)

LAT = latitude
LT = local solar times (hrs)
AP = Daily magnetic index
F 10.7 = Mean 10.7 radio flux (10^{-22} Wm^{-2} Hz^{-1}) over three solar ratations centered on period in question

[1]Hedin (1979).

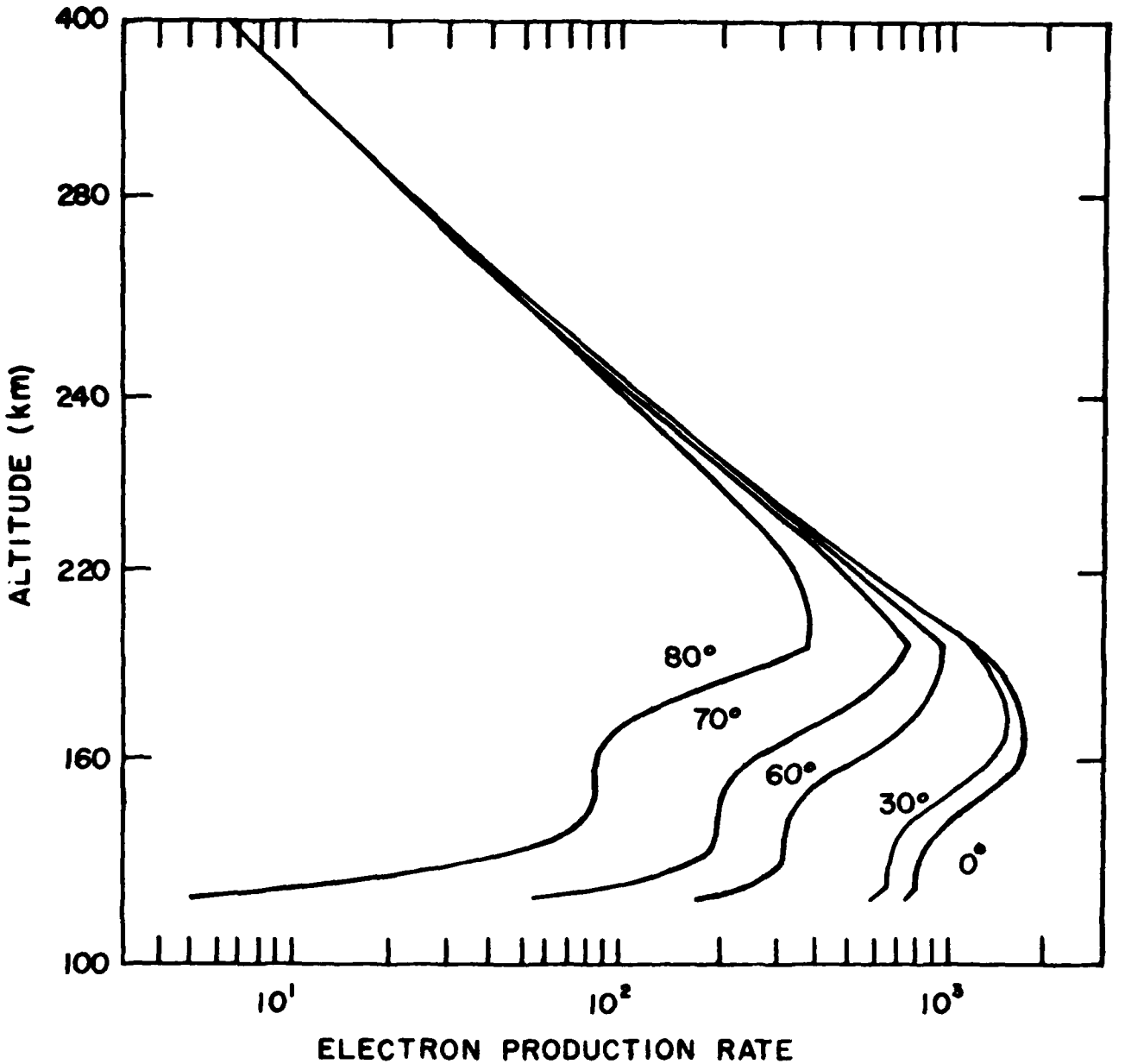


Figure 2. The electron production rates (electrons/cm^3/sec) at different solar zenith angles and altitudes.

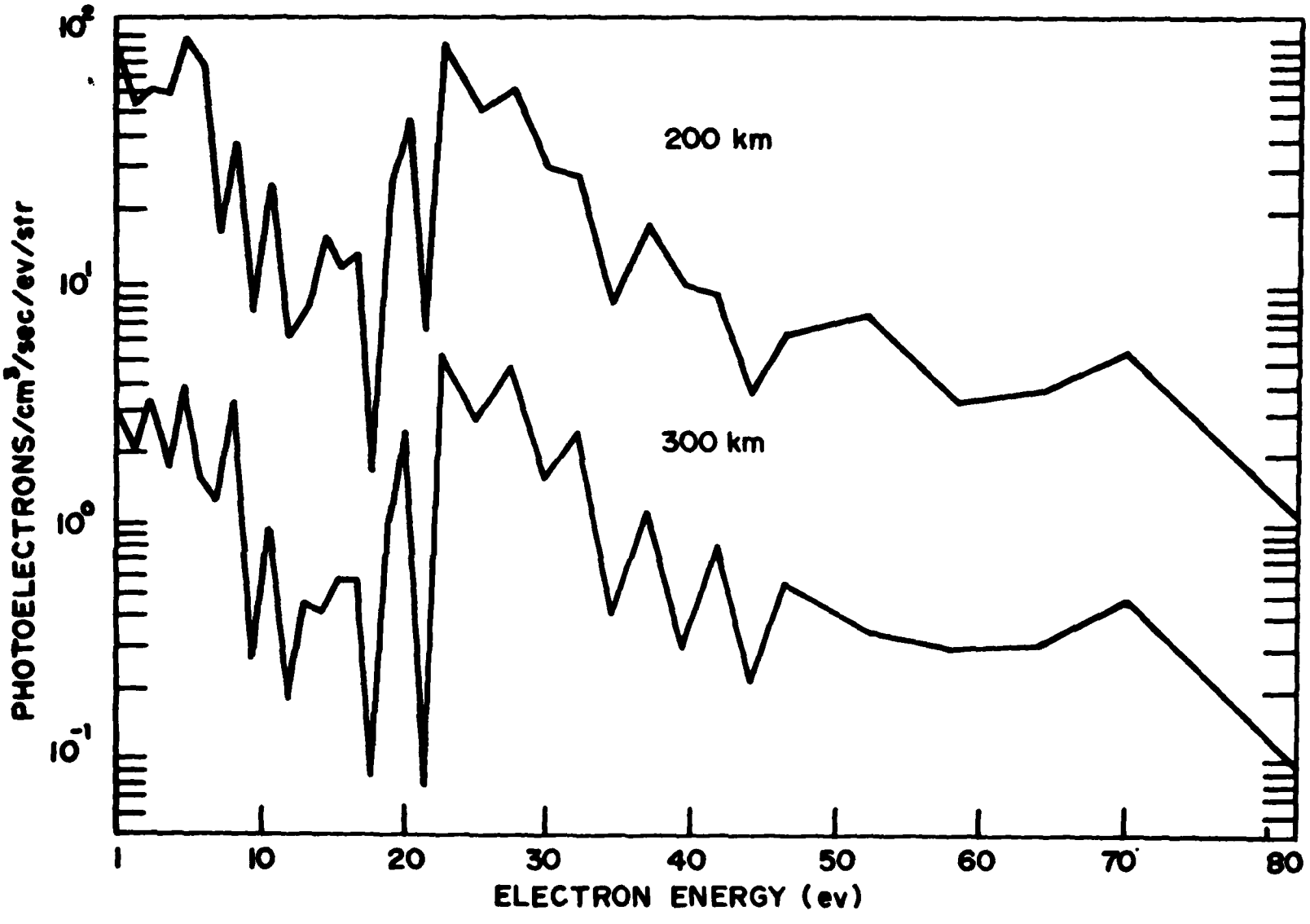


Figure 3. The primary electron spectrum at solar zenith 30°.

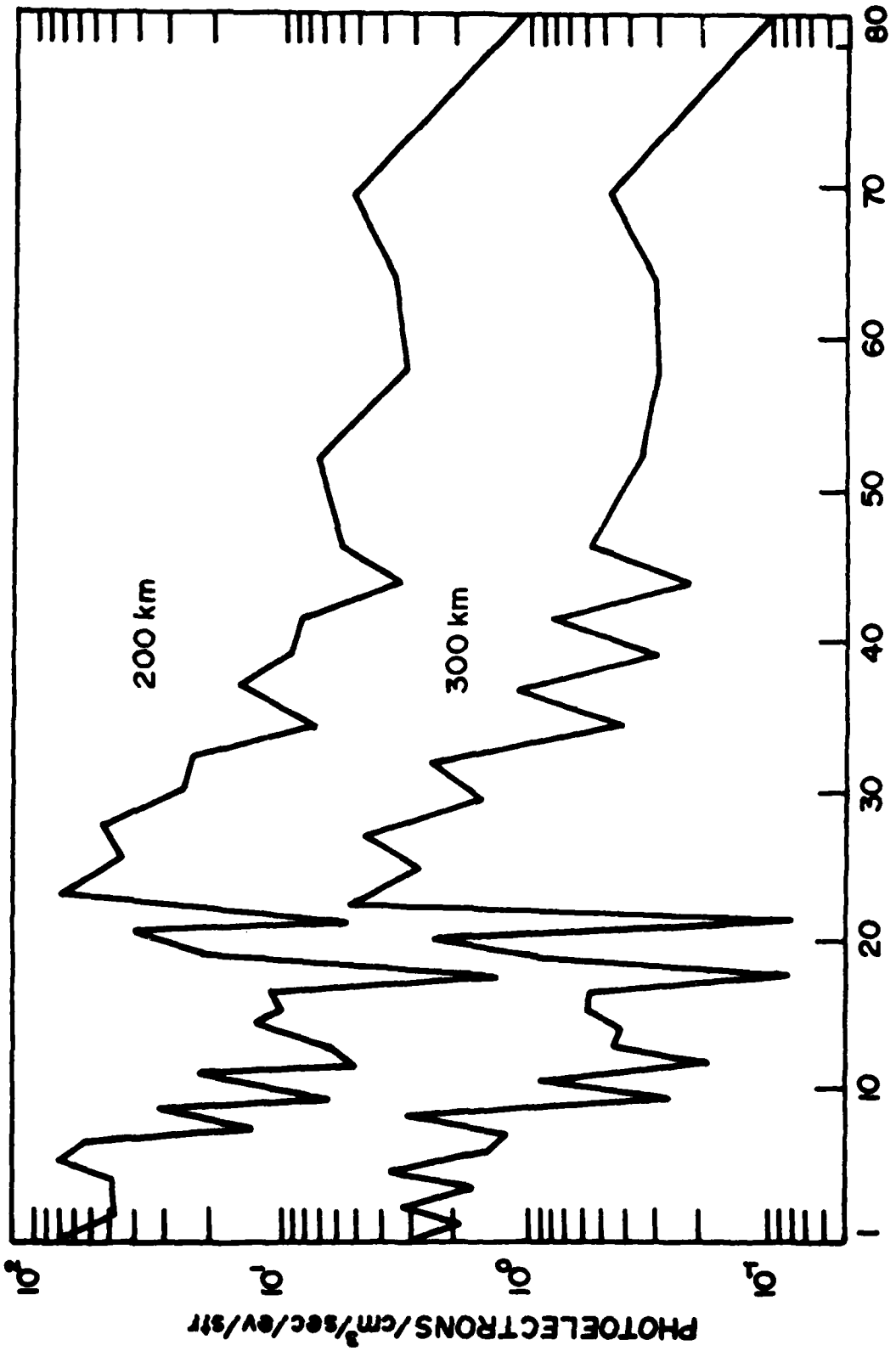


Figure 4. The primary electron spectrum at solar zenith 45°.

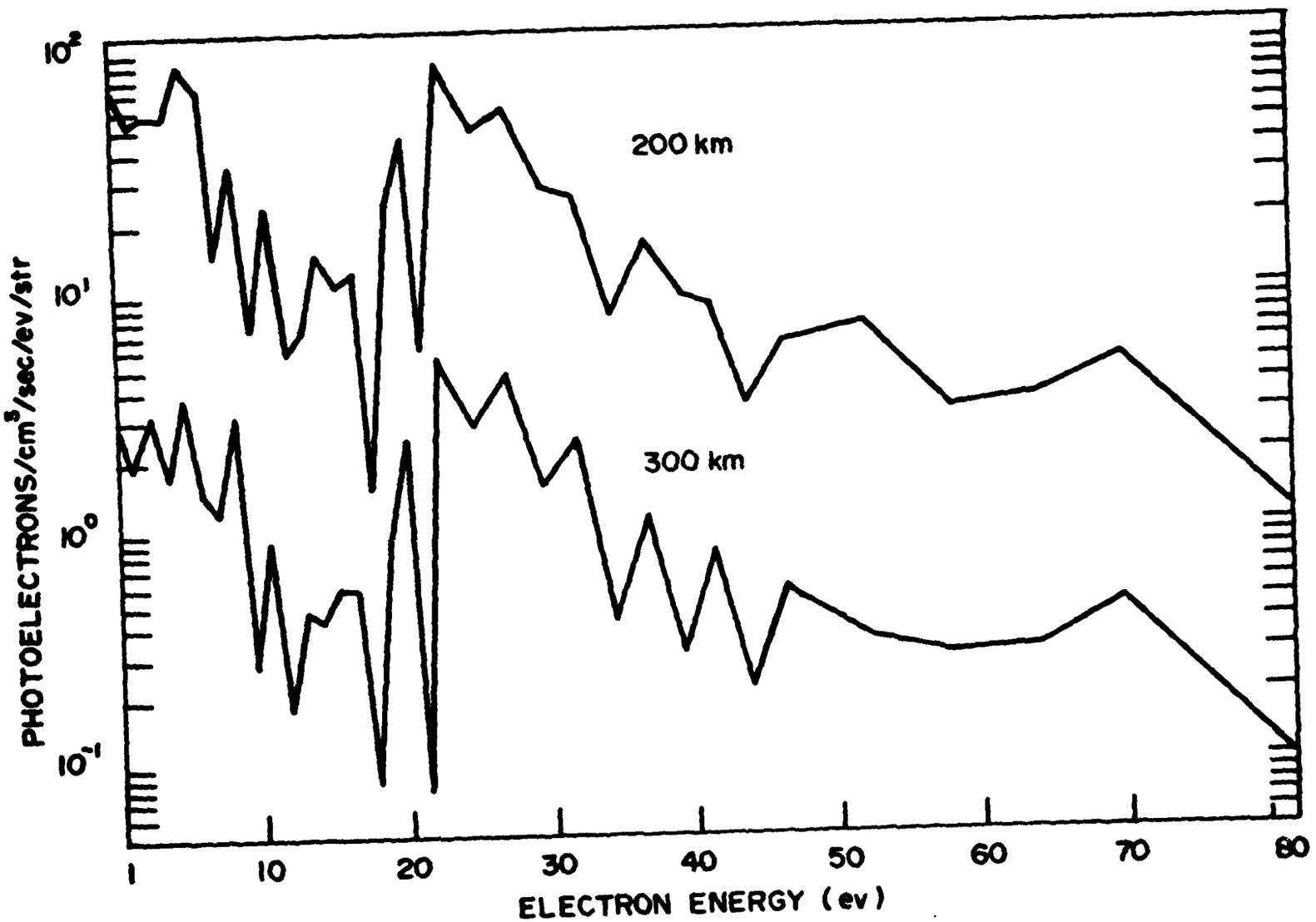


Figure 5. The primary electron spectrum at solar zenith 60°.

velocity and the density. By density we mean energy dependent density. The electron energy flux is shown in Fig. 6 at altitude of 300 KM, where it compares the fluxes with the local calculation obtained at the same conditions. As one can see below about 20 ev the transport fluxes are significantly lower than the local flux. It is in this region where the transport becomes important. The peak which has arisen at about 5 ev comes from the electron impact excitation of O(1D). The importance of O(1D) will be shown in the following section where we discuss the volume excitation rate.

To see the effect of transport we show the electron flux at 500 KM in Fig. 7, both for local and transport case. The transport fluxes are higher than local fluxes in the region below about 20 ev. In order to see the importance of transport we have made calculations of the electron flux for discrete electron energies as a function of altitude. This can be seen in Figures 8 and 9 where the transport fluxes are smaller than local fluxes at low altitudes and at high altitudes transport fluxes are larger than local fluxes. We also show the spectrum of electron flux at different altitudes as a function of electron energy in Fig. 10.

Table 2 summarizes the results of electron flux obtained from the experimental and theoretical data in the existing literature. There is a rather good agreement with the experimental work of Doering et al. (1975). In view of the expected differences in solar activity, atmospheric density, solar zenith angle, etc., we feel that the agreement is satisfactory.

In the following section we use our photoelectron energy flux to calculate the volume excitation rates of different important emission lines of the day airglow.

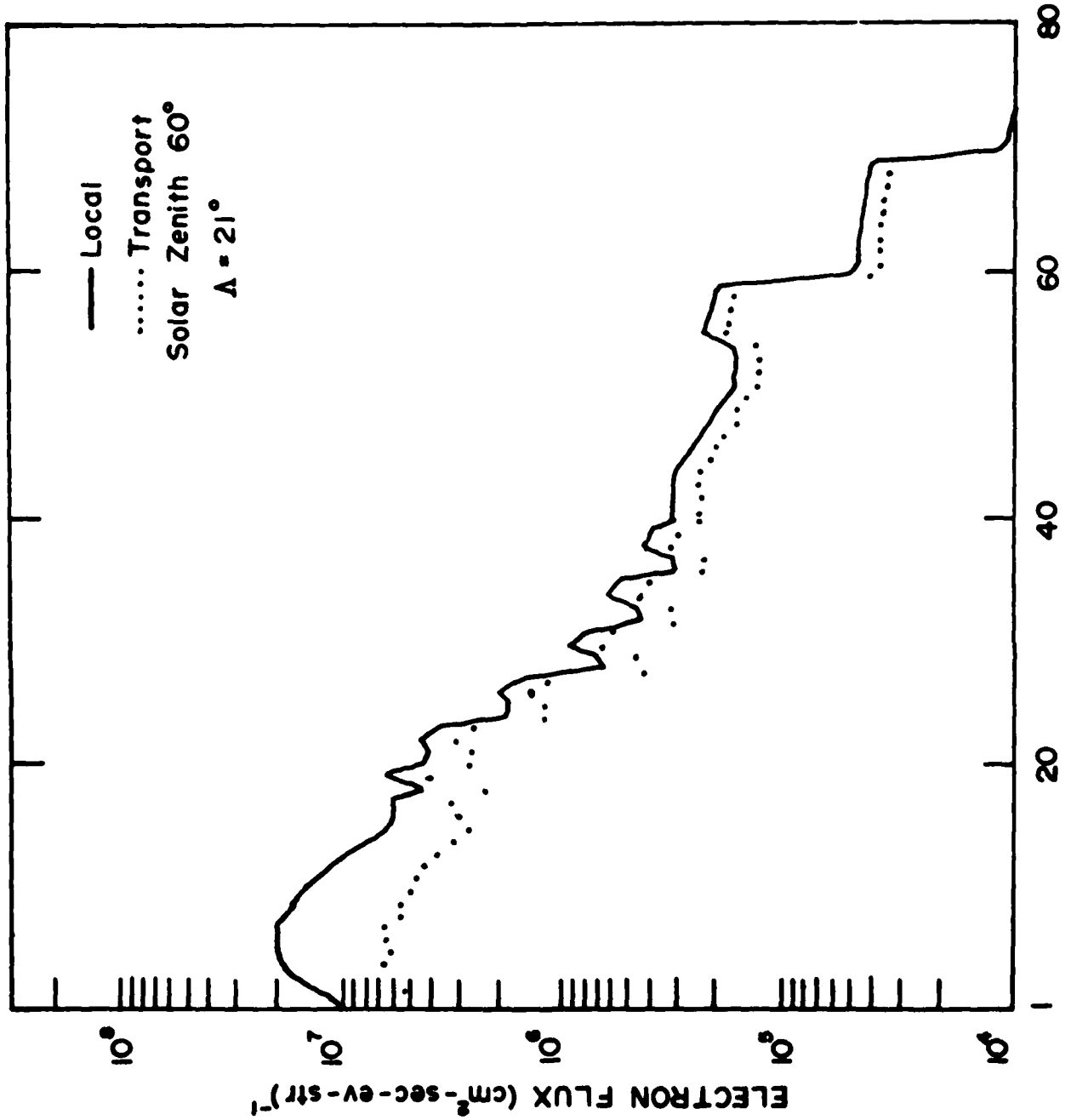


Figure 6. The comparison of local and transport flux at 300 KM.

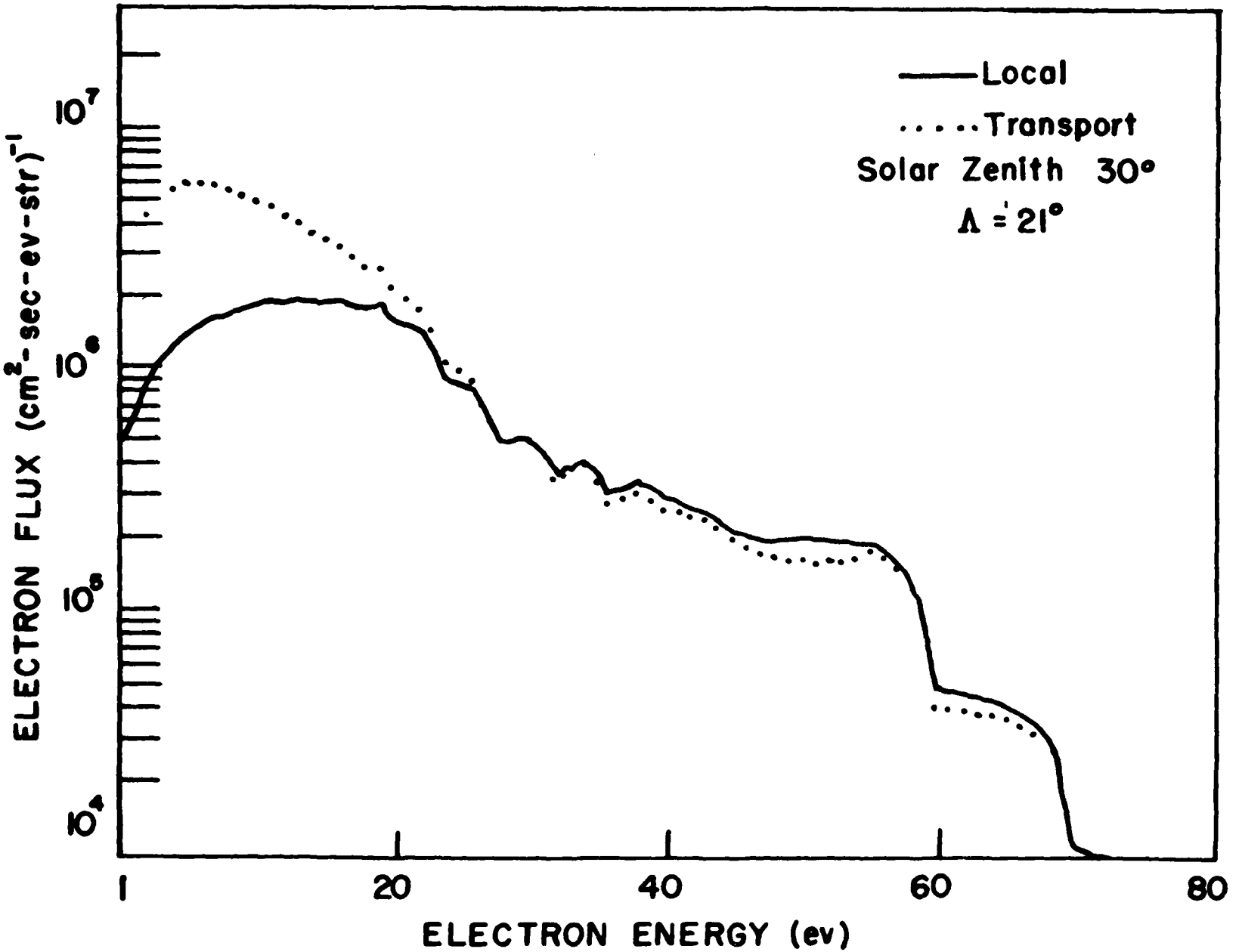


Figure 7. The comparison of local and transport flux at 500 KM.

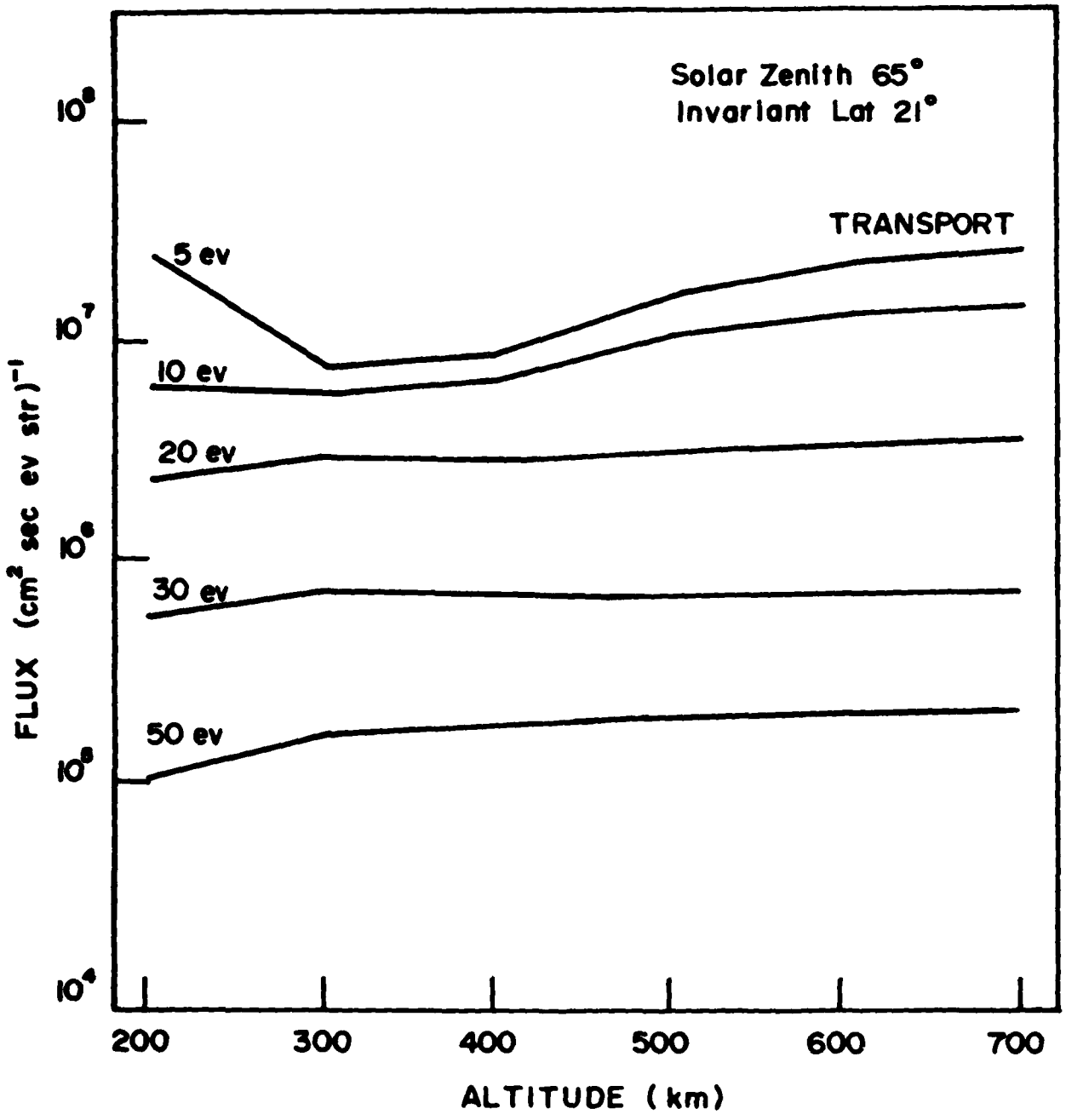


Figure 8. Transport fluxes at discrete electron energies as a function of altitude.

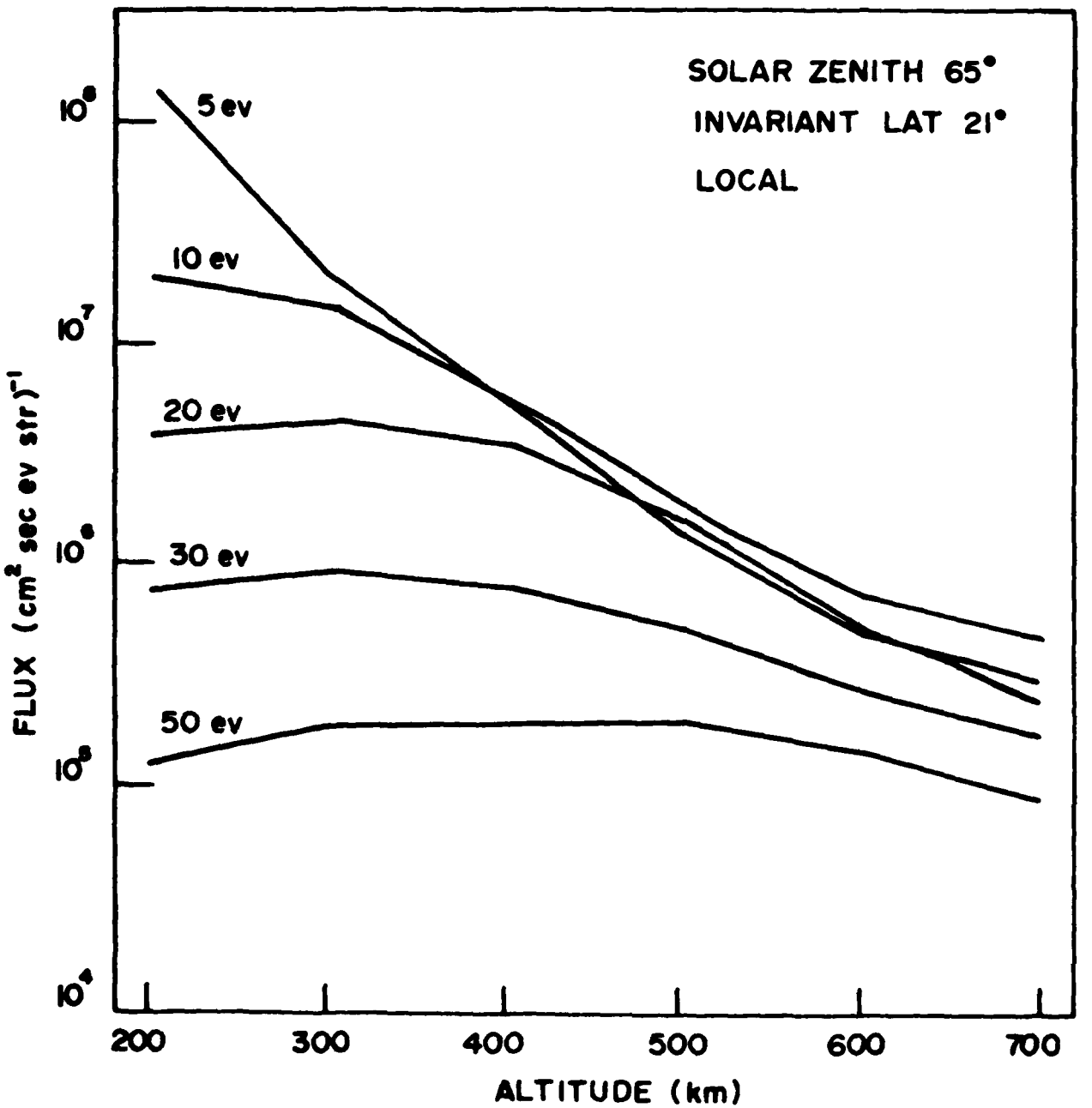


Figure 9. Local fluxes at discrete electron energies as a function of altitude.

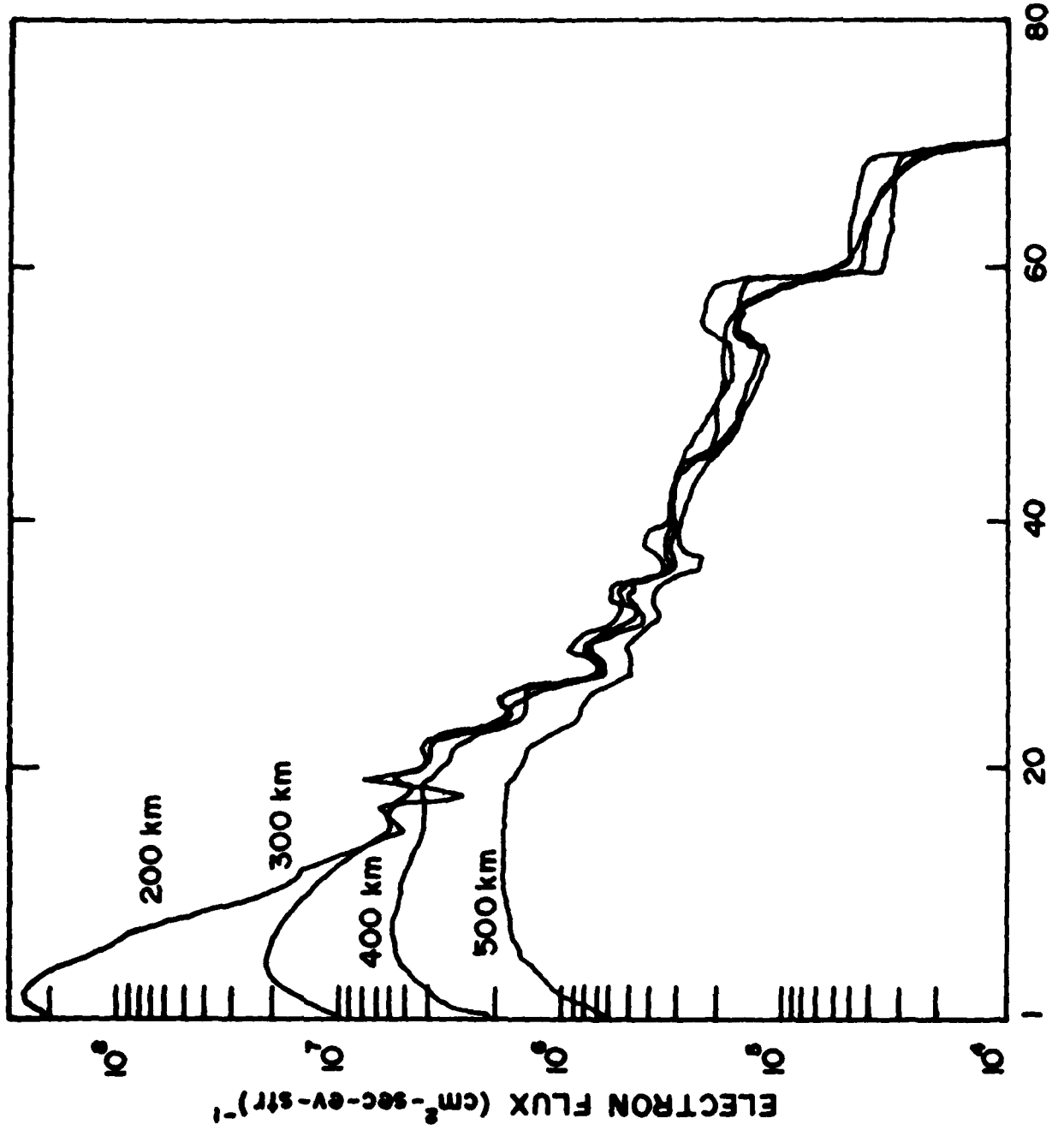


Figure 10. The electron flux for local solution at different altitudes at solar zenith 60°.

Table 2

Summary of the Results of Electron Flux

(cm^{-2} sec^{-1} ev^{-1} stv^{-1})

Reference	5 ev	10 ev	20 ev	30 ev	50 ev	ALT (KM)	Solar Zenith
Doering et al.* (1970)	2.8×10^7	2.8×10^6	1.5×10^6	----	----	200	60°
Doering et al.* (1975)	4×10^7	4×10^6	3×10^6	1×10^6	----	200	40-75°
Nagy and Banks (1970)	2.6×10^7	1.3×10^7	2×10^6	2×10^5	----	300	0°
Cicerone et al. (1973)	2×10^7	1×10^7	6×10^6	3×10^6	9×10^5	500	90°
This work	2.8×10^7	6×10^6	1.5×10^6	6×10^5	1×10^5	200	60°
This work	8×10^6	6×10^6	3×10^6	7×10^5	2×10^5	300	60°
This work	1.5×10^7	8×10^6	3×10^6	6×10^6	2×10^5	500	60°

*experimental data

E. Photoelectron Excitation

The volume excitation rate of a given line or band excited by electron impact can be calculated from a knowledge of the excitation cross section, and the density of neutral species. This rate can be expressed as (see Green and Barth, 1967):

$$I(Z) = n(Z) \int_{E_w}^{\infty} 4\pi F(Z,E)\sigma(E)dE$$

where the quantity I(Z) is the volume excitation rate ($cm^{-3}sec^{-1}$) at altitude Z, F(Z,E) is the electron energy flux at energy E and altitude Z (cm^{-2} sec^{-1} ev^{-1} stv^{-1} stv^{-1}), $\sigma(e)$ is the electron impact excitation, and E_w is the excitation threshold of neutral species.

To calculate the volume emission rate we need to know the branching ratio corresponding to emission lines and bands. For second positive system of nitrogen, for instance, the apparent cross sections are introduced for the calculation of volume emission rates. In this work the branching ratio of Jobe et al. (1967) is used for the second positive band of nitrogen and Green and Barth (1967) for atomic oxygen.

The electron impact excitation cross sections used in the calculations of volume excitation rates are from Green and Dutta (1967), Jackman et al. (1977) and Peterson et al. (1969). Tables 3, 4, 5 and 6 list the important excited and ionized states of the species N_2, O_2, He and O, respectively.

The volume excitation rates of different lines of atomic oxygen 5577A, 6300A, O (3S) 1304A, O(5S) 1356A are listed in Table 7, together with the experimental data of Zipf and Stone (1971). There is also close agreement of excitation rate O(1S) with the work of Schaeffer et al. (1972). There is an enhancement in O(1D) 6300A emission line as compared with the work of

Table 3

N_2 Excitation States

J	State	Threshold (ev)
1	$a^1 \pi_g$	8.40
2	$W^3 \Delta_u$	7.20
3	$A^3 \Sigma_u^+$	6.14
4	$B^3 \pi_g$	7.40
5	$C^3 \pi_u$	10.80
6	T 12.40	12.40
7	T 13.50	13.50
8	$N_2(VIB)^1$	0.43
9	$N_2(DIS)^2$	12.00

Ionization States

J	State	Threshold (ev)
1	$X^2 \Sigma_g^+$	15.58
2	$A^2 \pi_u$	16.73
3	$B^2 \Sigma_u$	18.75
4	$D^2 \pi_g$	22.00
5	DISC	25.00

1. VIB = Vibrational state

2. DIS - Dissociation state

Table 4

O_2 Excitation States

J	State	Threshold (ev)
1	$A^3 \Sigma_u^+$	4.50
2	$b^1 \Sigma_g^+$	1.62
3	$a^1 \Delta_g$	0.88
4	$a^4 \pi_u$ RY3	12.70
5	$a^4 \pi_u$ RY4	14.60
6	$a^4 \pi_u$ SUM	15.60
7	$A^2 \pi_u$ RY3	13.20
8	$A^2 \pi_u$ RY4	15.30
9	$A^2 \pi_u$ SUM	16.20
10	$b^4 \Sigma_g^-$ RY3	15.70
11	B COM RY3	19.60
12	T 8.40	8.40
13	T 9.90	9.90
14	LUMP.VIB	0.19

Ionization States

J	State	Threshold (ev)
1	$X^2 \pi_g$	12.20
2	$a^4 \pi_u$	16.10
3	$A^2 \pi_u$	16.90
4	$b^4 \Sigma_g^-$	18.20
5	B	23.00

Table 5

He Excitation State

J	State	Threshold (ev)
1	1S-2S	19.61
2	1S-3S	22.92
3	1S-4S	23.67
4	1S-3D	23.07
5	1S-2P	21.22
6	1S-3P	23.08
7	1S-4P	23.74
8	1S-5P	24.03
9	$1S-2S^3$	19.82
10	$1S-3S^3$	22.72
11	$1S-2P^3$	20.96
12	$1S-3P^3$	23.00
13	$1S-3D^3$	23.07

Ionization States

J	State	Threshold (ev)
1	1S	24.58

Table 6

O Excitation States

J	State	Threshold (ev)
1	$2P^4(1D)$	1.96
2	$2P^4(1S)$	4.18
3	3S 5S	9.15
4	4S 3S 3S	9.50
5	4S 3P 3P	11.00
6	4S 3P 5P	10.70
7	3D 3D	12.10
8	3D 5D	12.10
9	3S 3D	12.50
10	3S 1D	12.70
11	2D 3P 1P	14.00
12	3S 3P	14.10
13	2D 3P 3F	14.10
14	2D 3P 1F	14.10
15	2D 3P 3P	14.50
16	3D 3P	15.30
17	2P 3P 3P	15.80
18	2P 3P 1P	15.80

Ionization States

J	State	Threshold (ev)
1	4S	13.60
2	2D	17.20
3	2P	18.70

Table 7

Experimental and Theoretical Data on Excitation Rate of Atomic Oxygen in the Day Airglow at 200 KM

Reference	State	Excitation Rate (cm^{-3} sec^{-1})	Solar Zenith Angle
Prasad (1967)	O(5S)	32	60
Green and Barth (1967)		60	0
This work		5.5	65
Prasad (1967)	O(3S)	150	60
Green and Barth (1967)		70	0
Banks and Nagy (1970)		6.5	0
This work		156	65
Strickland and Donahue (1970)		160	60
Stewart (1970)		180	60
Zipf and Stone (1971)*		140	60
Hays and Sharp (1973)*	O(1S)	6	90
Schaeffer et al. (1972)*		5.6	65
This work		5	65
Feldman et al 1971)*		15	60
Schaeffer et al. (1972)*	O(1D)	60	86
This work		141	65

* Experimental data

Schaeffer et al. (1972). On the other hand there is a large reduction in the O(5S) excitation rate as compared with the work of Prasad (1969) and Green and Barth (1967).

The volume emission rates of different bands of molecular nitrogen are listed in Table 8, together with the experimental data of Doering et al. (1970), and the theoretical data of Green and Barth (1970). Good agreement is obtained with the experimental data of Doering et al. (1970), for the second positive band 3371A transition.

Our calculation of volume excitation rates is based only on electron impact excitation. Other indirect sources such as dissociative excitation or dissociative recombination are not taken into account.

There may be several reasons for the disagreement discussed above. We point out, however, that the numerical results for the volume excitation rate are very sensitive to the assumed values of electron impact cross sections.

Table 8

Experimental and Theoretical Data On Excitation Rate of

Molecular Nitrogen In the Day Airglow At 200 KM

Reference	State	Excitation Rate (cm^{-3} sec^{-1})	Solar Zenith Angle
Green and Barth (1967)	First negative (3971 A)	1.0	0
This work		1.77	65
Doering et al (1970)*	Second positive (3371 A)	14.0	60
This work		18.0	65
Green and Barth (1967)	Meinel band	2.5	0
This work		6.0	65

* experimental data

REFERENCES - CHAPTER II

1. Banks, P.M., and A.F. Nagy, Concerning the influence of scattering upon photoelectron transport and escape, J. Geophys. Res., 75, 1902 (1970).
2. Case, K.M., and P.F. Zweifel, Linear transport theory, Addison Wesley, Reading, Massachusetts (1967).
3. Cicerone, R.J., W.E. Swartz, R.S. Stolarski, A.F. Nagy and J.S. Nisbet, Thermalization and transport of photoelectrons: A comparison of theoretical approaches, J. Geophys. Res., 78, 6709 (1973).
4. Cook, C.R., and P.H. Metzger, Photoionization and absorption cross sections of O_2, N_2 in the 600 to 1000 Å region, J. Chem. Phys., 41, 321 (1964).
5. Dalgarno, A., R.J.W. Henry and A.L. Stewart, The photoionization of atomic oxygen, Planet. Space. Sci., 12, 235 (1964).
6. Doering, J.P., W.G. Fastie, and P.D. Feldman, Photoelectron excitation of N_2 in the Day Airglow, J. Geophys. Res., 75, 4787 (1970).
7. Doering, J.P., W.K. Peterson, C.O. Bastrom, and J.C. Armstrong, J. Geophys. Res., 80, 3934 (1975).
8. Feldman, P.D., J.P. Doering, and E.C. Zipf, Excitation of O(1S) atoms on the day airglow, J. Geophys. Res., 76, 3087 (1971).
9. Green, A.E.A., S.K. Dutta, Semi empirical cross sections for electron impacts, J. Geophys. Res., 72, 3933 (1967).
10. Green, A,E,S,, and C.A. Barth, Calculations of photoelectron excitation of the dayglow, J. Geophys. Res., 72, 3975 (1967).

11. Hays, P.B., W.E. Sharp, Twilight airglow 1. Photoelectons and OI 5577 Angstrom radiation, J. Geophys. Res., 78, 1153 (1973).

12. Hedin, A.E., Tables of thermospheric temperatures, density and composition derived from the satellite and ground based measurements, Goddard Space Flight Centre Report, Greenbelt, MD (1978).

13. Henry, R.J.W., Planet. Space Sci., 15, 1747, (1967).

14. Heroux, L., and H.E. Hinteregger, Aeronomic reference spectrum for solar UV below 2000 A^{o}, J. Geophys. Res., 83, 5305 (1978).

15. Jackman, C.H., R.H. Garvey and A.E.S. Green, Electron impact on the atmospheric gases, Updated cross section I, J. Geophys. Res., 82, 5081 (1977).

16. Jacobs, V., Phys. Rev., A3, 289 (1971).

17. Jobe, J.D., F.A. Sharpton, and R.M. St. John, Apparent cross sections of N_2 for electron excitation of the second positive system, J. Opt. Soc. Amer., 57, 106 (1967).

18. Peterson, L.R., S.S. Prasad, and A.E.S. Green, Semi empirical electron impact cross sections for atmospheric gases, Can. J. Chem., 47, 1774 (1968).

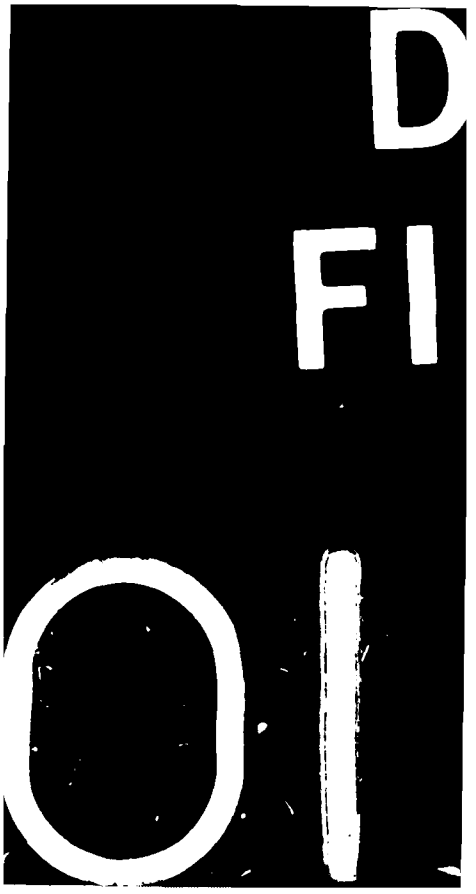
19. Schaeffer, R.C., P.D. Feldman, and E.C. Zipf, Dayglow OI λ 6300 and 5577 A lines in the early morning ionosphere, J. Geophys. Res., 77, 1828, (1972).

20. Stewart, A.I., Photoionization coefficient and photoelectron impact excitation coefficients in the daytime ionosphere, J. Geophys. Res., 75, 6333 (1970).

21. Strickland, D.J., and T.M. Donahue, Excitation and radioactive transport of OI 1304 A resonance radiation, 1, Dayglow, Planet. Space Sci., 18, 661 (1970).

22. Tohmatsu, E., T. Ogawa, and H. Tsuruta, Photelectronic processes in the upper atmosphere, I Energy spectrum of the primary photoelectron, Rep. Ions. Space. Res. Japan, 19, 482 (1965).

23. Zipf, E.C., and E.J. Stone, Photoelectron excitation of atomic oxygen resonances in the terrestrial atmosphere, J. Geophys. Res., 76, 6865, (1971).


D
FI
01